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Canadian Science Advisory Secretariat
Science Advisory Report 2012/050

ASSESSMENT OF NOVA SCOTIA (4VWX) SNOW CRAB

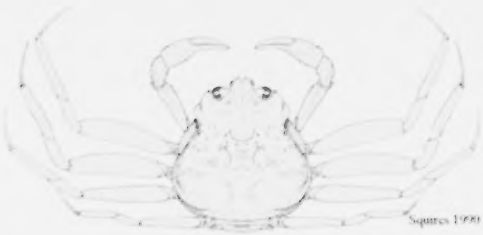

Figure 1. Map of the Scotian Shelf and Crab Fishing Areas (CFA).

Context

Snow crab have been a dominant macro-invertebrate in the Scotian Shelf Ecosystem (SSE) since the decline of the groundfish. They are observed in large numbers in deep, soft-bottom substrates ranging from 60 to 280 m and at temperatures generally less than 6°C. The SSE snow crab are on the southern-most extreme of their spatial distribution in the Northwest Atlantic.

The fishery has been in existence since the early 1970s in Nova Scotia. The management of the snow crab fisheries in the SSE was initially based on effort controls (season, license, trap limits) from 1982 to 1993 with harvesting during June-November of hard-shelled males larger than 95 mm carapace width (CW). Additional management measures were introduced from 1994 to 1999: IBQs (individual boat quotas), TACs (total allowable catches), 100% dockside monitoring, mandatory logbooks and at-sea monitoring by certified observers. In 2005, many Crab Fishing Areas (CFAs) and subareas were merged with the resulting divisions being N-ENS (formerly CFAs 20-22), S-ENS (CFAs 23, 24), and 4X (Figure 1).

In support of the fishery, DFO Maritimes Fisheries and Aquaculture Management requests from DFO Science an annual assessment of resource status. This document is a scientific overview of the assessment. An assessment of the status of 4VWX snow crab is based on fishery independent surveys using indicators of abundance, reproductive potential, recruitment, and exploitation rates. Commercial catch rates and other fishery statistics are reported. Harvest advice for the next year is provided.

This Science Advisory Report is from the 28 February 2012 Assessment of Nova Scotia (4VWX) Snow Crab. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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SUMMARY

- Landings in 2011 for N-ENS and S-ENS were 536 and 12,135 t, respectively, and they were 345 t in 4X for the 2010/11 season, representing decreases of 7%, 8% and an increase of 51% relative to the previous year.
- Total allowable catches in 2011 were 534, 12,120 and 346 t in N-ENS, S-ENS and 4X.
- Non-standardized catch rates in 2011 were 110.1 kg/trap haul in N-ENS, 106.4 kg/trap haul in S-ENS, and 38.3 kg/trap haul in 4X in 2010/2011 – representing increases of 100%, 4% and 6%, respectively, relative to the previous year.
- The shift towards earlier fishing seasons continues to improve soft shell crab handling rates in both N- and S-ENS. In N-ENS, the estimated soft shell crab discards declined from 3.5% in 2010 to 1.7% in 2011. In S-ENS, estimated soft shell crab discards decreased from 7.7% in 2010 to 5.5% in 2011. Soft shell discards in 4X are negligible.
- In 2011, the post-fishery fishable biomass in N-ENS was estimated to be 3,010 t relative to 3,170 t in 2010. In S-ENS, it was estimated to be 45,830 t relative to 47,270 t in 2010. In 4X, it was estimated to be 540 t, unchanged from 2010/2011.
- A large recruitment pulse has propagated through the system since the early 2000s. This pulse has now fully entered into fishable sizes. Continued recruitment to the fishery is expected for the next 2-3 years in N- and S-ENS. Recruitment beyond 2-3 years is possible due to the existence of animals in the 40-70 mm size classes in S-ENS. In N-ENS, a potential gap in recruitment is possible as was experienced in 2003-2005. Currently, 4X shows a lack of adolescent crab recruiting to the fishery in the next 2-3 years and may rely heavily on immigration for commercially exploitable crab.
- Egg production continues to decline after reaching highs in 2007/2008. Egg production is now below the long-term mean and is expected to remain so for 2-4 years due to a lack of maturing female crab, potentially affecting long-term recruitment.
- Bycatch levels, mostly of other crustacean species, are less than 0.01% of annual landings in ENS and approximately 0.9% in 4X. By-catch continues to be extremely low in this fishery.
- High relative densities of predators were found in areas with high densities of immature snow crab. This predation may lower future recruitment to the fishable biomass.
- The surface area of potential snow crab habitat was above the 1998-2011 mean in all areas.
- A reference points-based Precautionary Approach is being adopted in this fishery. The Limit Reference Point is 25% of carrying capacity and the Upper Stock Reference is 50% of carrying capacity. The target Removal Reference is 20% of the fishable biomass in each area and the Removal Reference is not to exceed F_{MSY}. Secondary indicators are used to inform management decisions under the harvest control rules linking the stock references to harvest strategies.
- In N-ENS, modelled fishing mortality was estimated to be 0.15 from 2009 to 2011. Good recruitment in the short-term and significantly reduced soft-shell discards result in a positive outlook. The fishable biomass was above the Upper Stock Reference (3.26 kt in 2011), i.e. in the "healthy" zone, where harvest rates between 10% and 20% are considered sustainable in this fishery. A status quo to a marginal increase in harvest strategy (rate) is recommended.
- In S-ENS, modelled fishing mortality was estimated to be 0.22 in 2010 and 2011. Good recruitment suggests a positive outlook. Continued reduction of soft shell crab interactions will benefit the long-term outlook of the fishery. The fishable biomass was above the Upper Stock Reference (35.0 kt in 2011), i.e. in the "healthy" zone, where harvest rates between 10% and 30% are considered sustainable in this fishery. A status quo to a marginal increase in harvest strategy (rate) is recommended.

- In 4X, assuming the Total Allowable Catch is reached, fishing mortality in 2011/2012 is expected to be 0.44. The modelled fishable biomass was above the Upper Stock Reference (0.63 kt in 2011), i.e. in the "healthy" zone, where harvest rates between 10% and 30% are considered sustainable in this fishery. As recruitment into the 2012/2013 season is uncertain, a decreased harvest strategy (rate) is recommended.

BACKGROUND

Species Biology

Snow crab (*Chionoecetes opilio*, O. Fabricius) is a subarctic species with a distribution from northern Labrador to near the Gulf of Maine. Habitat preference is for soft mud bottoms. Smaller crabs are found in more complex habitats with shelter. Commercial crab in large numbers are found at depths from 60 to 280 m and temperatures from -1 to 6°C on the Scotian Shelf. Temperatures greater than 7°C are known to be detrimental to snow crab. The primary food items of crab are shrimp, fish (capelin and lumpfish), starfish, sea urchins, worms, detritus, large zooplankton, other crabs, ocean quahaug, molluscs, sea snails and sea anemones. Predators of snow crab are halibut, skates (especially thorny skate), cod, seals, American plaice, squids, and other crabs. Crab in the size range of 3 to 30 mm CW are particularly vulnerable to predation, as are soft-shelled crab in the spring moulting season.

Fishery

The snow crab fishery in eastern Canada began in 1960 with incidental by-catches by groundfish draggers near Gaspé, Quebec. Its development was slow until the 1980s, when it began expanding rapidly to become one of the largest fisheries in Canada in terms of landings and landed value. On the Scotian Shelf, the fishery has been in existence since the early 1970s. Total landings increased to record-levels of approximately 10,000 t each year in the early 2000s (Figure 2). Landings in 2011 for N-ENS and S-ENS were 536 and 12,135 t, respectively, and they were 345 t in 4X for the 2010/11 season, representing decreases of 7%, 8% and an increase of 51% relative to the previous year. TACs (Total allowable catches) in 2011 were 534, 12,120 and 346 t in N-ENS, S-ENS and 4X (Figure 2, Tables 1-3).

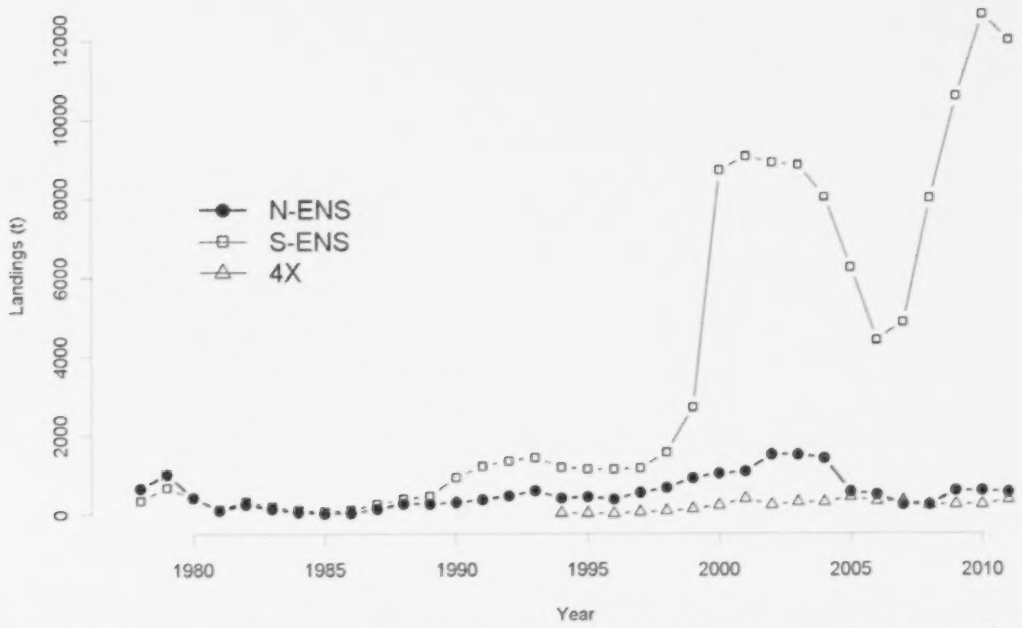


Figure 2. Temporal variations in the landings (t) of snow crab on the Scotian Shelf. The landings follow the TACs with little deviation, so the TACs are not shown. For 4X, the year refers to the starting year of the season.

Table 1. Summary of snow crab fisheries in N-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (x1000 trap hauls)
1997	74	540	534	23.3	22.9
1998	74	660	657	41.6	15.8
1999	78	900	899	54.8	16.4
2000	79	1,015	1,017	68.3	14.9
2001	80	1,065	1,066	94.3	11.3
2002	80	1,493	1,495	101	14.8
2003	80	1,493	1,492	76.8	19.4
2004	79	1,416	1,418	60.6	23.4
2005	78	566	562	30.6	18.4
2006	78	487	486	35.6	13.7
2007	78	244	233	23.6	9.9
2008	78	244	238	33.7	7
2009	78	576	579	75.7	7.6
2010	78	576	576	55	10.5
2011	78	534	536	110.1	4.8

Table 2. Summary of snow crab fisheries in S-ENS.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (X1000 trap hauls)
1997	59	1,163	1,157	50.9	22.7
1998	67	1,671	1,558	68.9	22.6
1999	-	2,700	2,700	71.1	38
2000	158	8,799	8,701	85	102.4
2001	163	9,023	9,048	87.8	103.1
2002	149	9,022	8,891	111.7	79.6
2003	145	9,113	8,836	98.6	89.6
2004	130	8,241	8,022	105.6	76
2005	114	6,353	6,407	109.5	58.5
2006	114	4,510	4,486	90.9	49.4
2007	115	4,950	4,942	100.1	49.3
2008	115	8,316	8,253	96.1	85.9
2009	116	10,800	10,760	89.6	118.8
2010	116	13,200	13,150	102.5	128.3
2011	116	12,120	12,135	106.4	118.8

Table 3. Summary of snow crab fisheries in 4X.

Year	Licenses	TAC (t)	Landings (t)	CPUE (kg/trap haul)	Effort (X1000 trap hauls)
1997/08	4		42		
1998/09	4		70		
1999/2000	4		119		
2000/01	6		213		
2001/02	8	520	376		
2002/03	9	600	221	10.1	21.9
2003/04	9	600	289	12.7	22.8
2004/05	9	600	413	20.3	20.8
2005/06	9	337.6	306	28.6	10.8
2006/07	9	337.6	317	27.7	11.5
2007/08	9	230	220	18.1	12.1
2008/2009	9	230	229	28.4	8
2009/2010	9	230	229	36	6.4
2010/2011	9	346	345	38.3	9
2011/2012	9	346	346	40.0	8.6

In 2011, the spatial distribution of landings was focused on mid-shore and offshore areas in S-ENS and on the "inside" (not Glace Bay Hole) area in N-ENS (Maps 1, 2). There was negligible effort on the offshore-slope areas in 2011. Movement of commercial crab between all areas has been observed.

Non-standardized catch rates in 2011 were 110.1 kg/trap haul in N-ENS, 106.4 kg/trap haul in S-ENS, and 38.3 kg/trap haul in 4X in 2010/2011 – representing increases of 100%, 4% and 6%, respectively, relative to the previous year (Tables 1-3, Figure 3, Map 3).

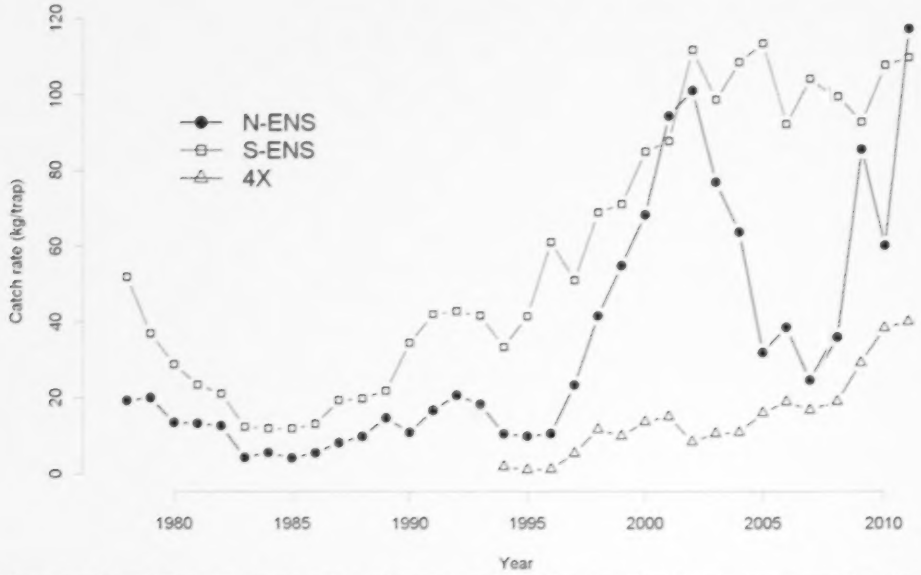


Figure 3. Temporal variations in catch rates of snow crab on the Scotian Shelf, expressed as kg per trap haul. Trap design and size have changed over time. No corrections for these varying trap-types nor soak time and bait-type have been made.

In N-ENS, carapace condition 1 (CC1) crab represented 2% of the total observed catch in 2011 and CC2 crab represented 2% of the total catch (Figure 4), with no appreciable change from 2010 but drastic decreases from 2007. These decreases are largely attributable to the creation of a spring fishery in 2008. After a successful trial in 2008, the majority of landings (>85%) from N-ENS were caught during the spring season from 2009 to present (with a high of 91% in 2010). Less than 1% of the catch was CC1 or CC2 in the 2011 spring fishery. There has been a shift towards larger animals in N-ENS catches in the past two years suggesting higher survival of immature crab (lack of handling mortality of soft-shelled crab) and a decreased dependence on newly recruited animals. The size distribution of the catch now closely resembles that of S-ENS though with less CC1 and CC2 crab.

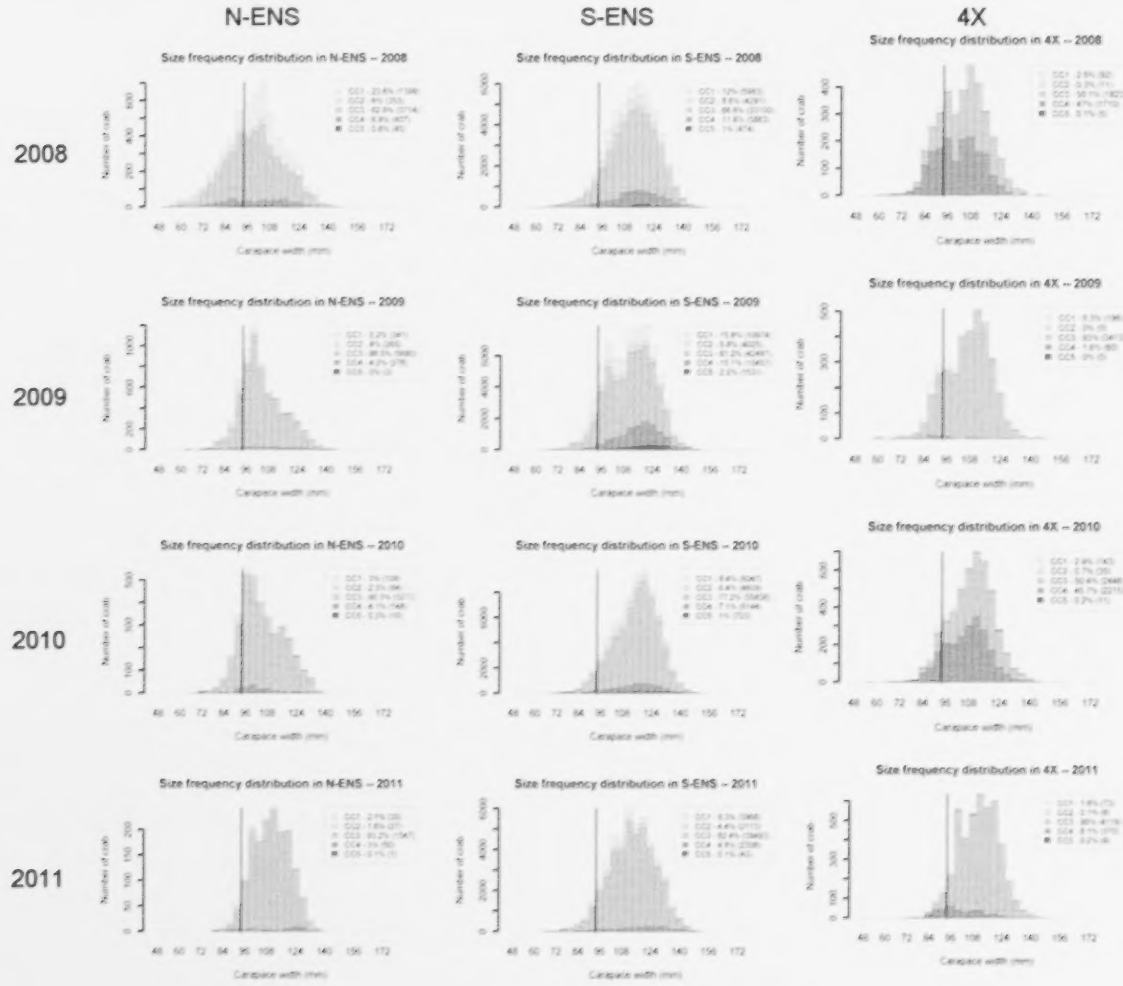
In S-ENS, the occurrence of CC1 and CC2 crab in 2011 (8% and 4%, respectively) was similar to that observed in 2010, 8 and 6%, respectively (Figure 4). Hard shell crab dominated the catch with 82% CC3 and 5% CC4.

CC5 crab represented approximately 1% or less of the total observed catch in all areas. The abundance estimates of old male crab (CC5) has been stable in the long-term record and below the detection limit on the Scotian Shelf surveys.

In 4X for the 2010/11 season, CC1 and CC2 crab represented a total of 3% and 1% of the total catch, comparable to those of 2009/2010. A shift away from a CC3 dominated catch to one split between CC3 and CC4 suggests an aging population structure, but observer error is suspected to confound these results from the past fishing season. The data from 4X are not directly comparable to ENS as their fishing season is disjunct from that of N- and S-ENS. This winter 4X fishery continues to show negligible levels of soft crab.

In N-ENS, the estimated soft shell crab discard (% of total landings) declined further from 3.5% in 2010 to 1.7% in 2011. This continues an improving trend in soft shell crab rates since 2007 in N-ENS when 111% of the landings were estimated to have been discarded as soft shell crab. In S-ENS, estimated soft shell discards decreased from 7.7% in 2010 to 5.5% of the TAC in 2011.

The shift towards earlier fishing seasons continues to improve soft shell crab handling rates in both N- and S-ENS to previously unseen levels. Soft shell discards in 4X are negligible, in large part due to a fall / winter fishery.


N-ENS
S-ENS
4X
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Size frequency distribution in N-ENS -- 2008
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Size frequency distribution in S-ENS -- 2011
Size frequency distribution in 4X -- 2011

Figure 4. Size frequency distribution of all at-sea-observer monitored snow crab broken down by carapace condition. For 4X, the year refers to the starting year of the season. Vertical lines indicate 95 mm CW, minimum legal commercial size.

ASSESSMENT

Stock Trends and Current Status

Fishable Biomass

The fishable biomass (Table 4, Figure 5, Map 4) is defined as that segment of the snow crab biomass that is male, mature, larger than 95 mm CW and hard-shelled (with a durometer measure of 68 or greater).

In N-ENS, the post-fishery fishable biomass of snow crab in 2011 was 3,010 t (95% CI: 2,690 to 3,380 t) relative to 3,170 in 2010.

In S-ENS, the post-fishery fishable biomass of snow crab in 2011 was estimated to be 45,830 t (95% CI of: 42,700 to 49,200 t) relative to 47,270 t in 2010.

In 4X, the pre-fishery fishable biomass in 2011/2012 was 540 t (with a 95% CI of 320 to 930 t), unchanged from 2010/2011.

Table 4. Survey index fishable biomass and landings entering into the assessment model and harvest rates. Harvest rate is landings applied on Total Biomass (Survey Index + Landings) in a single year. Target harvest rate is the landings applied on the fishable biomass of the previous year (Landings/ Fishable Biomass$_{(t-1)}$).

	Year	Fishable Biomass (kt)	TAC (kt)	Landings (kt)	Harvest Rate (%)	Target Harvest Rate (%)
N-ENS	2004	1.55	1.416	1.418	47.7	
	2005	1.35	0.566	0.562	29.4	36.5
	2006	1.41	0.487	0.486	25.7	36.1
	2007	1.90	0.244	0.233	10.9	17.3
	2008	2.89	0.244	0.238	7.6	12.8
	2009	3.40	0.576	0.579	14.5	19.9
	2010	3.17	0.576	0.576	15.4	16.9
	2011	3.01	0.534	0.536	15.1	16.8
S-ENS	2004	26.62	8.241	8.022	23.2	
	2005	23.81	6.353	6.407	21.2	23.9
	2006	24.95	4.51	4.486	15.2	18.9
	2007	32.05	4.95	4.942	13.4	19.8
	2008	43.75	8.316	8.253	15.9	25.9
	2009	49.66	10.8	10.645	17.7	24.7
	2010	47.27	13.2	13.15	21.8	26.6
	2011	45.83	12.12	12.135	20.9	25.6
4X	2004/05	0.16	0.6	0.413		
	2005/06	0.13	0.336	0.306	56.1	
	2006/07	0.14	0.336	0.317	71.0	
	2007/08	0.27	0.23	0.22	37.8	
	2008/09	0.54	0.23	0.229	30.3	86.8
	2009/10	0.65	0.23	0.229	26.2	43.0
	2010/11	0.54	0.346	0.345	45.2	53.5
	2011/12	0.54	0.346	0.346	39.1	64.0

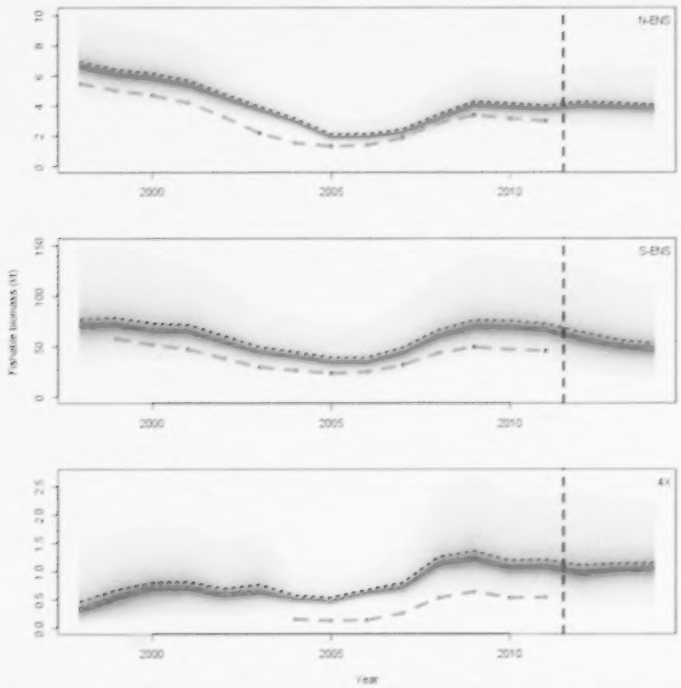


Figure 5. Time-series of the fishable biomass index (red dashed lines) and fishable biomass estimated from the biomass dynamics model (blue stippled lines). Fishable biomass estimates are presented (gray) with the darkest area being medians and the 95% CI. A three year projection assuming a constant exploitation strategy of 20% is also provided.

Recruitment

The index of recruitment (CC1 and CC2 crab, >95 mm CW) to the fishable biomass has been high though with a decreasing trend in S-ENS since 2007 and relatively high and stable in N-ENS since 2009. Recruitment remains extremely variable in 4X (Figure 6). Recruitment in S-ENS was observed throughout the area, with the highest levels focused in Misaine and Middle Banks and south of Sable Island (Map 5). Recruitment in N-ENS was observed throughout the area.

A large recruitment pulse has propagated through the system since the early 2000s (Figure 7). This pulse has now fully entered into fishable sizes. Positive signs of adolescent crab suggest continued recruitment to the fishery for the next 2 to 3 years in N- and S-ENS. Recruitment beyond 2-3 years is possible due to the existence of animals in the 40-70 mm size classes in S-ENS. In N-ENS, these size classes are not observed, and a potential gap in recruitment is possible as was experienced in 2003-2005. Currently, 4X shows a lack of adolescent crab recruiting to the fishery in next 2-3 years and may rely heavily on immigration for commercially exploitable crab.

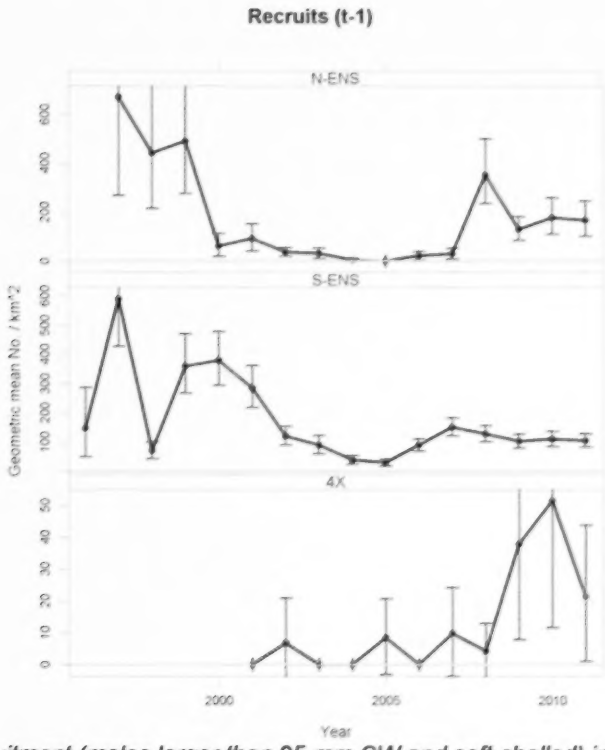


Figure 6. Expected recruitment (males larger than 95 mm CW and soft-shelled) into the mature stage in the next year. As surveys are conducted in the autumn (since 2002/2003), the majority of recruitment into the fishable biomass has already occurred. This figure shows the additional recruitment expected that has not yet become part of the fishable biomass. Error bars are 95% confidence intervals about the estimated density.

Reproduction

Female snow crab abundance has continued to decline in all areas but remains above long-term means. The associated egg production continues to decline after reaching highs in 2007/2008 (Figure 9). Egg production is now below the long-term mean and is expected to remain so for 2 - 4 years due to a lack of maturing female crab (Figure 8), potentially affecting long-term recruitment. Isolated concentrations of mature females exist in all areas with a more diffuse distribution around the CFA 23 / 24 management line and along the southwest coast of Nova Scotia (Maps 6, 7). Sex ratios (proportion female) are now male-dominated in N-ENS, are stabilizing at low levels in S-ENS and are stable at more moderate levels in 4X (Figure 10).

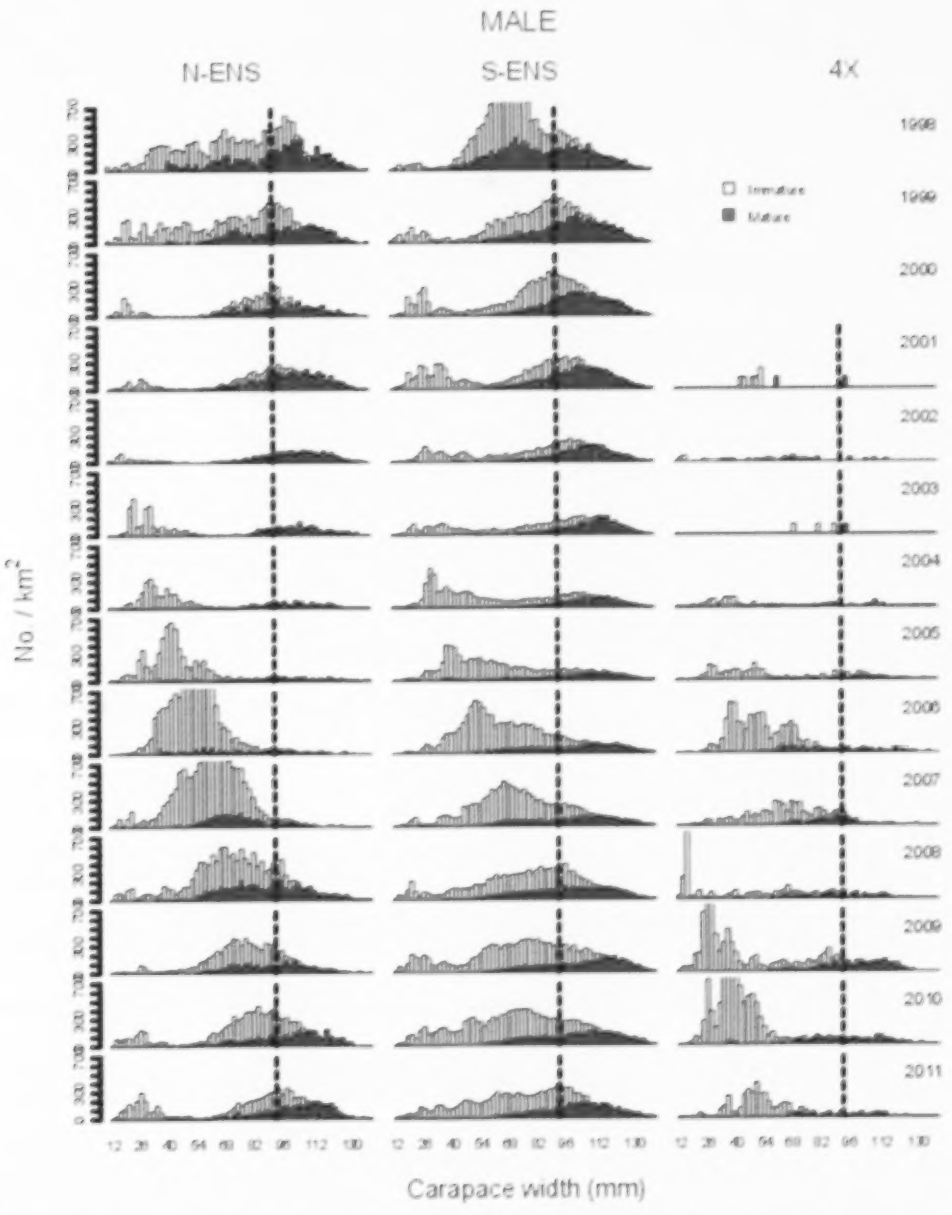


Figure 7. Size-frequency histograms of carapace width of male snow crabs. Note the relatively uniform distribution of adolescent crab across all size classes in S-ENS as compared to other areas and previous patterns in S-ENS. Note that for S-ENS and 4X (but not N-ENS) the spatial extent of the surveys have changed over time, making a direct comparison of numerical density inappropriate. This figure provides information about the relative numbers within a given year. The vertical line represents the legal size (95 mm).

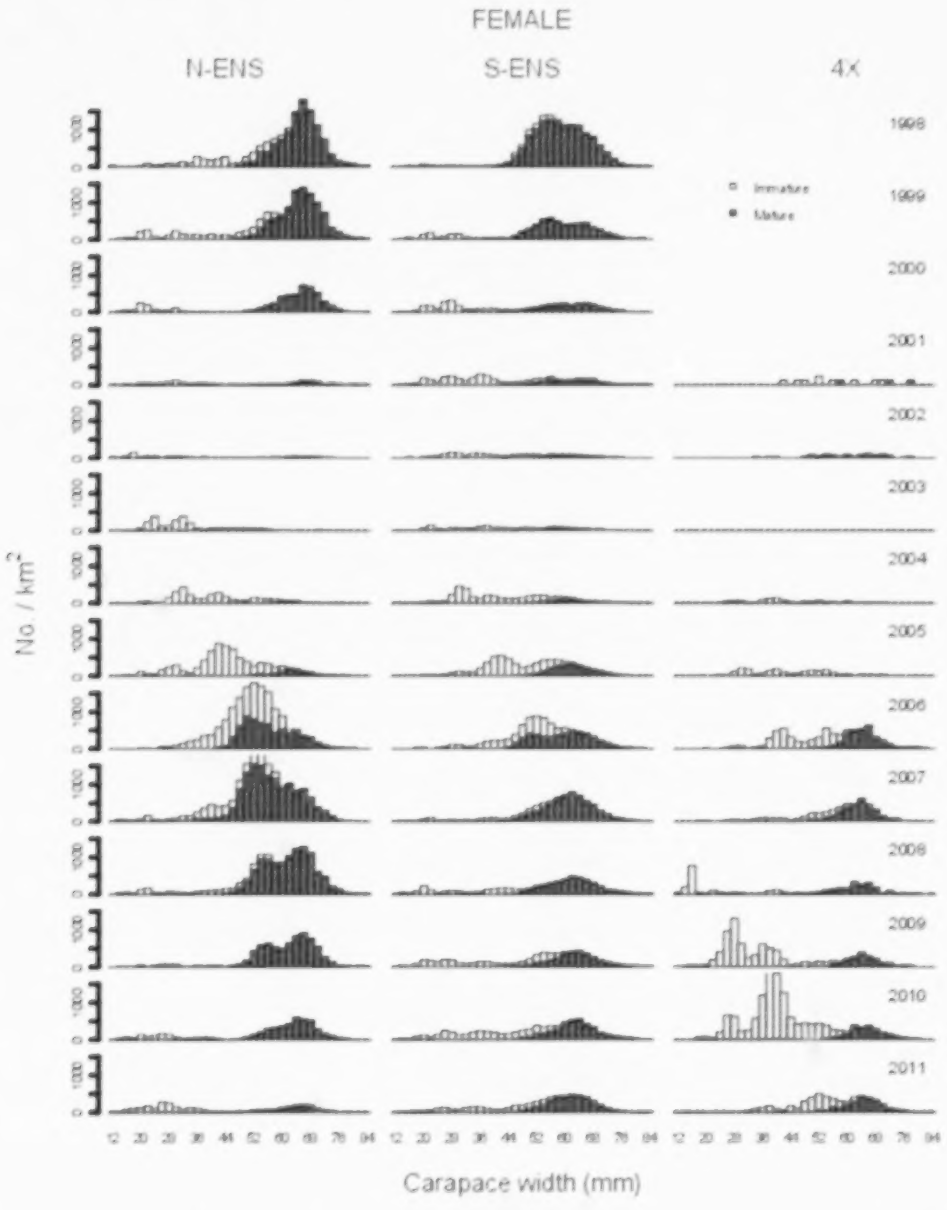


Figure 8. Size-frequency histograms of carapace width of female snow crabs. Note that for S-ENS and 4X (but not N-ENS) the spatial extent of the surveys have changed over time, making a direct comparison of numerical density inappropriate. This figure provides information about the relative numbers within a given year.

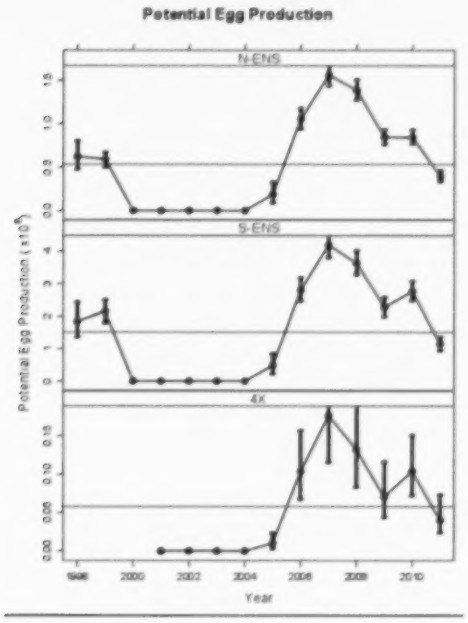


Figure 9. Potential egg production of snow crab on the Scotian Shelf.

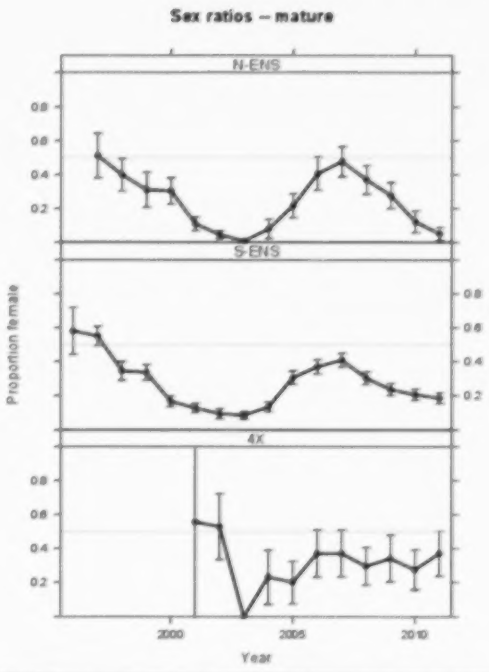


Figure 10. Sex ratios (proportion female) of mature snow crab. Since 2000, most of the Scotian Shelf was uniformly male dominated.

Fishing Mortality

The abundance estimates of old male crab (CC5) has been stable in the long-term record and below the detection limit on the Scotian Shelf. Their low representation in the survey data and the fishery-observed data may be indicative of high mortality rates (fishery-based and/or natural).

Fishing mortality in N-ENS has historically been in the range of 0.1 to 0.6, peaking in 2004 (Figure 11). In 2011, fishing mortality is estimated to have been 0.15 (95% CI: 0.10, 0.21; harvest rate[1] of 14.0%), it is has been and relatively constant since 2009. The low harvest rate in 2008 was implemented to help reduce soft-shell handling.

Fishing mortality for S-ENS has historically ranged from 0.05 to 0.25, peaking in 2003-2004 and in 2010 (Figure 11). In 2011, fishing mortality is estimated to have been 0.22 (95% CI: 0.14, 0.34; or a harvest rate[1] of 20.5%), which is a small decrease from 0.23 in 2010. Localized exploitation rates are likely higher as not all areas where biomass estimates are provided are fished (e.g., continental slope areas, and western, inshore areas of CFA 24). Such localised over-harvesting is a concern because this increases the potential catchability of soft shell crab, which leads to greater handling mortality of new recruits into the fishable biomass and also loss of habitat grounds to competitors of snow crab (e.g., other crab species).

In 4X, fishing mortality has historically ranged from 0.2 to > 1, peaking in 2005 and only declining towards target levels since 2008 (Figure 11). In 2010/2011, fishing mortality was 0.44 (95% CI: 0.26, 0.68; harvest rate[1] of 35.6%), an increase from 0.28 the previous year. Localized

[1] Harvest rate = $1 - e^{-F}$

exploitation rates are likely to be higher, since the computed exploitation rates incorporate biomass from throughout the 4X area and not just the fishing grounds.

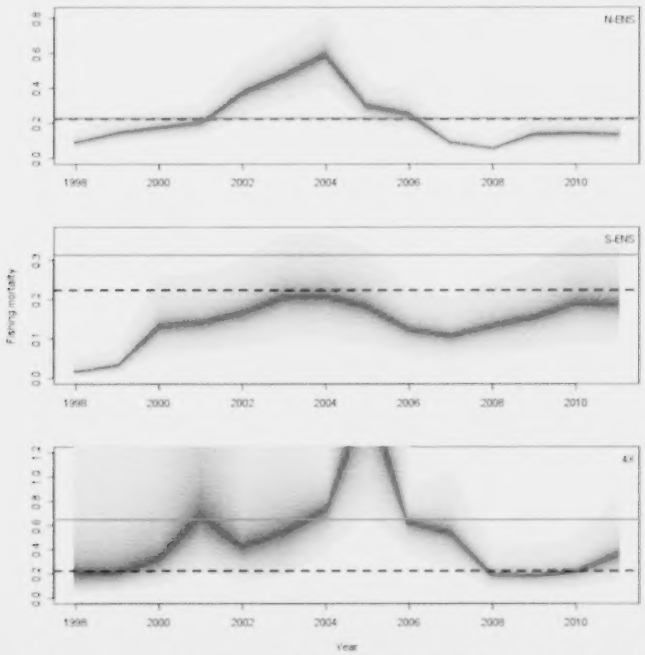


Figure 11. Time-series of fishing mortality for N-ENS, S-ENS and 4X, respectively. Posterior density distributions are presented in gray, with the darkest line being the median with 95% CI. The red line is the estimated F_{MSY} and dark stippled line is the 20% harvest rate.

Ecosystem Considerations

A multivariate summary of key environmental (climatic), social, economic and fishery-related indicators (Figure 12) suggests that a suite of coherent changes have occurred on the Scotian Shelf since the early 1990s. These latter changes include: changes in the relative abundance of groundfish (declining) and invertebrates (increasing; e.g., snow crab) and their associated landings and landed values; socio-economic changes in ocean use such as oil and gas exploration and development (increasing); and Gross Domestic Product (GDP) associated with the oil and gas sector as well as total Nova Scotia GDP (increasing). Further, the physiological condition of many groups of fish has also been declining and the total number of shellfish closures have increased with time, as has the amount of seismic activity. Increasing ocean colour, abundance of diatoms and dinoflagellates, and declining abundance of *Calanus finmarchicus* were also influential to this axis of variation. The temporal differences along this axis of variation indicate that coherent systemic changes of socio-economic and ecological indicators occurred in the early 1990s associated with the groundfish collapse. A trend towards a return to long-term states is evident since an extreme point in 2008 (Figure 13). Thus, while the current "ecosystem state" is one that continues to be amenable to the high abundance of snow crab, there is an increased concern that there may be another systemic ecosystem change in the near future. An increase in groundfish stocks would increase predation upon snow crab stocks. Other consequences of such an ecosystem shift could exist for snow crab.

Importantly, temperature-related changes were generally orthogonal (independent) to the above changes, e.g., bottom temperatures and variability in bottom temperatures, bottom oxygen concentrations, and sea ice coverage. The temporal variations of this axis indicate that the

current ocean-climate has returned to its average state after a decade-long divergence from the late 1980s to the late 1990s. Temperature anomalies in particular were considered a potential cause of the increase in abundance of snow crab in the late 1990s due to snow crab being cold-water stenotherms. However, the habitat analysis suggests that potential snow crab habitat existed in the 1970s and 1980s, suggesting that their recent increase in abundance is primarily driven by non-environmental factors such as reduced predation mortality and increased survival of early life stages (see section on Environmental Variability).

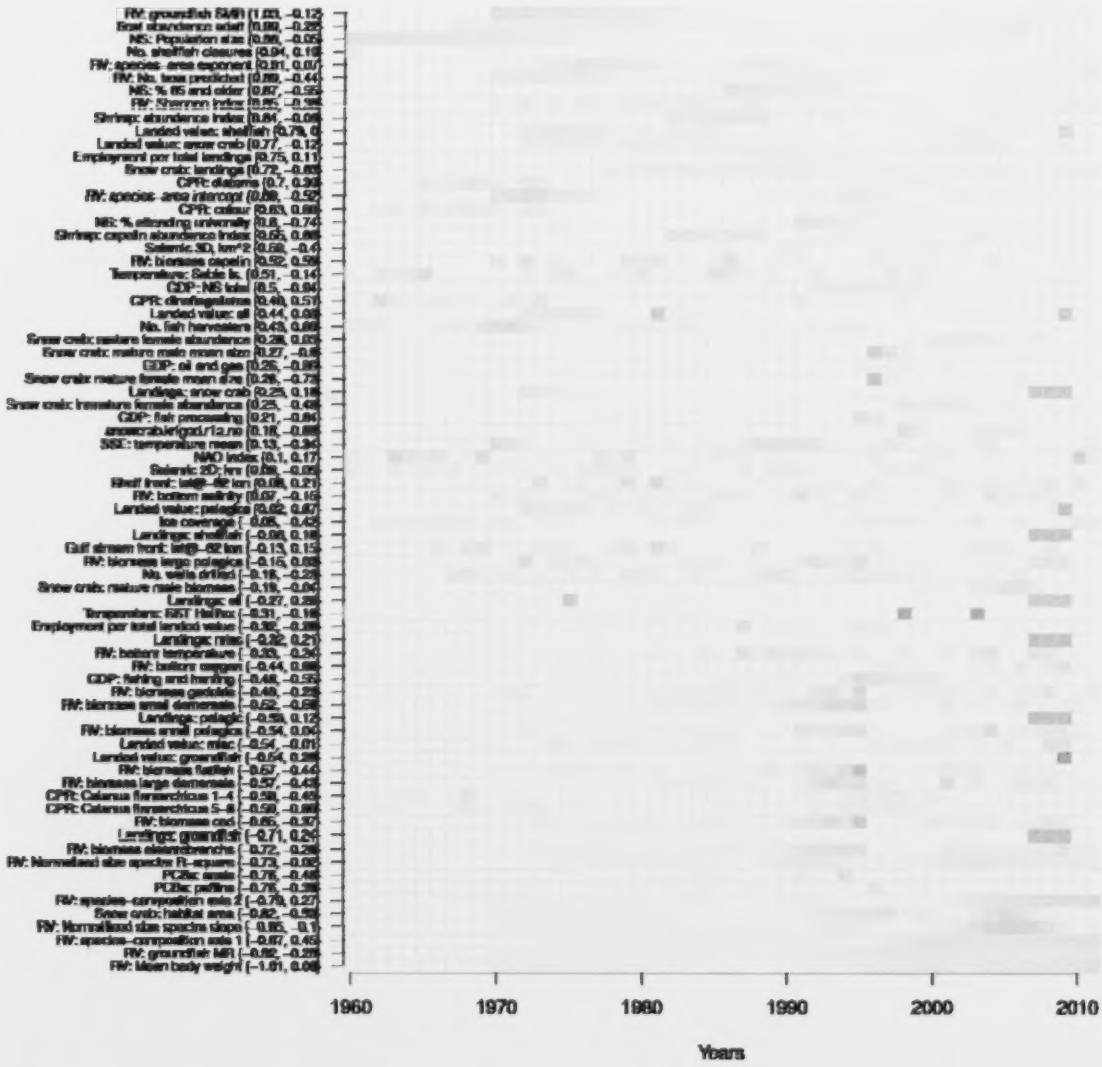


Figure 12. Sorted ordination of anomalies of key social, economic and ecological patterns on the Scotian Shelf relevant to snow crab. Red indicates below the mean and green indicates above the mean. Original in colour.

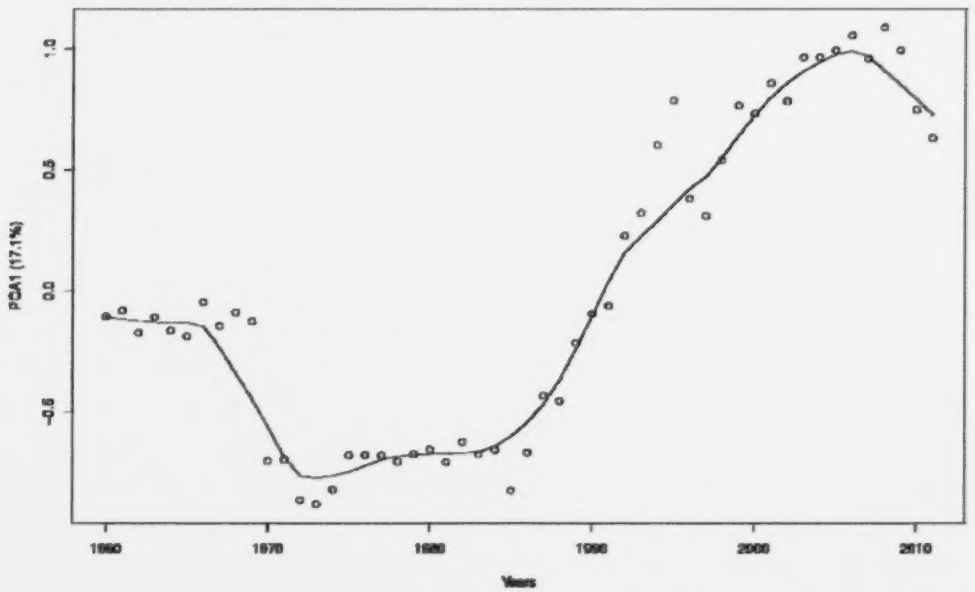


Figure 13. First axis of variation in ordination of anomalies of social, economic and ecological patterns on the Scotian Shelf.

Environmental Variability

The surface area of potential snow crab habitat in the SSE was above the 1998-2011 mean in all areas; actually closer to the maximum for this reference period. Based upon the longer historical projections from 1970 to 1998, potential snow crab habitat was present on similar scales to that observed in the present regime (Figure 14). In N-ENS, the surface area of predicted snow crab habitat has varied between 5.4 to 9.0 × 10^3 km^2 and is currently at higher levels than the 1998-2011 mean. For S-ENS, the surface area of potential habitat has varied with similar oscillations, ranging from between 53 to 75 × 10^3 km^2 and is currently at higher levels than the 1998-2011 mean. In 4X, the southern-most limit of the distribution of snow crab, potential habitat has been variable, ranging from 3.6 to 9.5 × 10^3 km^2 and is currently at the maximum in the 1998-2011 period.

Temperature variations within the areas of potential habitat appeared to be robust (Figure 15). Average bottom temperatures in 2011 were generally warmer in N-ENS and S-ENS though colder in 4X compared to those in 2010. Within the area that may be considered potential snow crab habitat, average bottom temperatures were generally stable with long-term means of 3.3, 3.7, and 5.7°C in N-, S-ENS, and 4X, respectively (Figure 15). Average bottom temperatures in 2011 were close to the long-term means and mostly in phase throughout the three subareas in the long-term record.

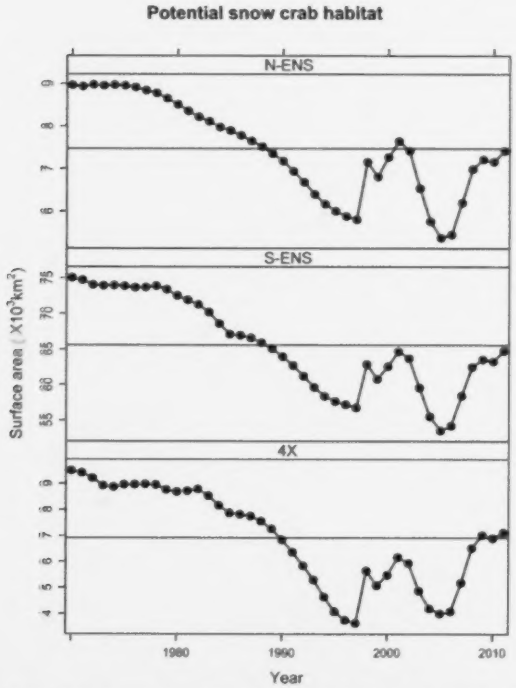


Figure 14. Annual variations in the surface area of potential snow crab habitat. The horizontal line indicates the long-term arithmetic mean surface area within each subarea. The estimates for the period from 1998 to the present are based upon snow crab surveys while those prior to 1998 are projected using incomplete data (and so less reliable). The surface area of potential habitat is presently above the mean (actually close to the maximum) for the 1998-2011 period.

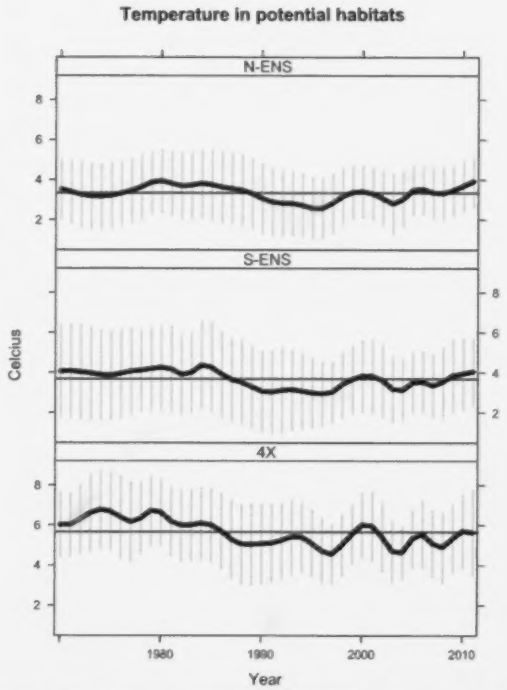


Figure 15. Annual variations in bottom temperature within potential snow crab habitat. The horizontal line indicates the long-term arithmetic mean temperature within each subarea. Error bars are 1 standard deviation. See caveats in Figure 14.

Bottom-up (Resource Limitation)

Food items such as northern shrimp are found in concentrations comparable to the long-term average in most core areas of S-ENS (based on snow crab trawl survey; Map 8).
Near the ocean surface, there has been a trend towards increased ocean colour, which is an index of chlorophyll concentrations. Therefore, total primary production may be increasing (in the form of diatoms and dinoflagellates). This is likely enhanced by the reduction in abundance of *Calanus finmarchicus*, an important zooplankton link in the pelagic food web. Whether this elevated primary production reaches the detrital system is not yet known.

Top-down (Predation)

High relative densities of predators (based on snow crab trawl survey) were found in areas with high densities of immature snow crab (for example, thorny skate; Map 9). This predation may lower future recruitment to the fishable biomass.

Seals are considered by fishers to be a predator of snow crab, and their continued increase in abundance (Figure 12) is a source of concern for many fishers and some scientists. While seals have been observed with snow crab in their stomachs, it should also be emphasized that high

concentrations of snow crab are currently found in the immediate vicinity of Sable Island, an area where the abundance of grey seals is extremely high. The evidence indicating that seals have a negative influence upon the snow crab population, therefore, seems to be minimal. In fact, it is quite possible that seals may be having a positive influence by physically importing food and food waste (organic matter) from other more outlying areas to the immediate vicinity of Sable Island. This would indirectly "feed" the snow crab and also protect them from potential predators of crab (in both early pelagic and benthic stages). Seal predation of groundfish would lower potential lateral competition for snow crab food resources.

Lateral (Competition)

Large mature males stabilize the snow crab population by maintaining and occupying prime crab habitat. Large mature males keep at bay potential competitors such as other crab species or even groundfish, serve as strong mates for the current population pulse of mature females, and are protectors of the smaller females. Their over-exploitation can have numerous negative biological consequences.

An important consequence of the extended period of low numbers of females to males (Figure 10) observed in the early-2000s throughout the Scotian Shelf is that poor egg and larval production in the system likely occurred for at least a four to five year period. Poor egg production may occur again in the mid-2010s. Stabilisation of such strong oscillations in abundance into the future may be possible if reproduction of the currently available females is supported by an adequate population of large males.

Human Influences

Oil and gas development/exploitation continues to occur on the Scotian Shelf near to, or upstream of, major crab fishing grounds and population centers in both N- and S-ENS. The effects of seismic methods of exploration upon potentially vulnerable components of the snow crab population (eggs, larvae, soft-shelled crab) and the long-term biological effects of development upon this long-lived species are still not known (DFO 2004, Courtenay et al. 2009). Despite such uncertainties and objections from the fishing industry, DFO Science and NGOs (Boudreau et al. 2009), seismic exploration occurred in November 2005 and July 2010 immediately over the Glace Bay Hole and the shallows of the Sydney Bight (Hunt Oil 2005) where immature and female crab are generally abundant. Due to a concern that the low abundance of snow crab in the Glace Bay Hole area may be related to these activities, even with no exploitation of the area, further investigations have been requested. Other seismic studies have occurred in the area, including a seismic study over Sidney Bight in July 2010 (Husky Oil 2010), as well as studies of Artimon Bank, Banquereau Bank, and the Stone Fence in 2009 and 2010 (RPS Group 2010).

Undersea cables have been identified by fishers as a source of concern, in particular, the Muskrat Falls subsea cable in N-ENS. At present, their effects upon snow crab are unknown.

St Anns Bank has been identified as an Area of Interest for designation as a Marine Protected Area. The complex consequences of this designation are still to be determined. The presence of a refuge from fishing activities is potentially positive as it could serve as a fallow area. However, if the reserve is disproportionately beneficial to other organisms, be they predators or prey of snow crab, the effects upon snow crab could be mixed. The long-term effects of the Area of Interest/Marine Protected Area cannot be determined at this point.

Bycatch

Bycatch levels in the SSE snow crab fishery have been extremely low in the long-term record. Estimates of bycatch in this fishery are extrapolated from at-sea observer estimates. In ENS, estimates of bycatch were 0.01% of snow crab landings. 4X shows higher (relative to ENS) bycatch rates at 0.9 % of snow crab landings. The majority of bycatch for all areas is composed of other invertebrate species (e.g., northern stone crab and American lobster) for which higher survival rates can be expected after being released as compared to fin fish discards. In the last three years, observers reported one leatherback turtle as having been entangled in buoy lines. This turtle was reported to be released alive though bleeding. Additionally, a dead basking shark was observed entangled in buoys lines in 2011.

Bycatch of snow crab from other fisheries is still not quantified. Trawls can increase mortality, especially upon the soft-shelled phases of snow crab, though the lack of trawl fisheries (other than shrimp trawling) in the majority of snow crab habitat on the Scotian Shelf limits this potential damage. Bottom damage from the placement of snow crab traps is thought to be minimal.

CONCLUSIONS AND ADVICE

High catches of soft shell crab are a potential issue in N- and S-ENS (but not 4X due to their offset fishing season), depending on the balance of spring or summer fishing activities. Timely responses from industry to avoid fishing in areas showing potential or actual high incidence of soft crab must continue if unnecessary mortality of future recruits is to be averted. An earlier season in N- and S-ENS appeared to significantly reduce soft-shell handling and should continue whenever possible in future years.

In N-ENS, modelled fishing mortality was estimated to be 0.15 from 2009 to 2011. Good recruitment in the short-term and significantly reduced soft-shell discards result in a positive outlook. The fishable biomass was above the Upper Stock Reference (3.26 kt in 2011), i.e. in the "healthy" zone, where harvest rates between 10% and 20% are considered sustainable in this fishery. A status quo to a marginal increase in harvest strategy (rate) is recommended.

In S-ENS, modelled fishing mortality was estimated to be 0.22 in 2010 and 2011. Good recruitment suggests a positive outlook. Continued reduction of soft shell crab interactions will benefit the long-term outlook of the fishery. The fishable biomass was above the Upper Stock Reference (35.0 kt in 2011), i.e. in the "healthy" zone, where harvest rates between 10% and 30% are considered sustainable in this fishery. A status quo to a marginal increase in harvest strategy (rate) is recommended.

In 4X, assuming the Total Allowable Catch is reached, fishing mortality in 2011/2012 is expected to be 0.44. The modelled fishable biomass was above the Upper Stock Reference (0.63 kt in 2011), i.e. in the "healthy" zone, where harvest rates between 10% and 30% are considered sustainable in this fishery. As recruitment into the 2012/2013 season is uncertain, a decreased harvest strategy (rate) is recommended.

MANAGEMENT CONSIDERATIONS

The prompt and careful return of immature crab to the water is an important conservation measure that will enhance the mid-term (2-3 year) sustainability of this fishery. This is a measure that needs to continue.
DFO is moving to formalize the Precautionary Approach (PA) policy and framework for key harvested stocks managed by DFO. The primary components of the framework are:

1. Reference points and stock status zones (Healthy, Cautious and Critical).
2. Harvest reference points and harvest control rules.
3. The need to take into account uncertainty and risk when developing reference points and developing and implementing decision rules.

Many existing measures and fishing practices in the Scotian Shelf snow crab fishery are inherently "precautionary". These include (among others):

- No removal of female crab. Reproductive potential of spawning stock biomass is not disrupted. Most removals of males occur after mating and sub-legal mature crab (able to reproduce) are never removed.
- Conservative exploitation strategies have generally been the norm, especially in recent years.
- Refugia from directed fishing pressures exist in the Gully MPA, along the continental slope, and much of the western inshore portion of CFA 24.
- Immature and soft-shelled (newly-moulted, easily damaged) crab are not harvested and handling mortality is minimized via area closures and at-sea observer monitoring of soft-shell incidence helping to maximize the potential yield per animal to the biomass.

A reference points-based PA approach is being adopted in this fishery. Reference points for snow crab are based on the estimated "carrying capacity" of fishable biomass of each area.

These estimates are:
- N-ENS: 6.52 {5.07, 8.49} kt
- S-ENS: 70.0 {48.8, 98.1} kt
- 4X: 1.25 {0.91, 1.75} kt

The following biomass-based reference points are used in the Scotian Shelf snow crab fishery:
- Limit Reference Point (LRP): 25% of carrying capacity
- Upper Stock Reference (USR): 50% of carrying capacity

Stocks are considered to be in a "healthy state" when above the USR, in a "cautious state" when between the USR and the LRP, and in a critical state when below the LRP. Snow crab stocks on the Scotian Shelf are all above the USR (Figure 16). "Precautionary" management measures are based on this indicator of stock health.

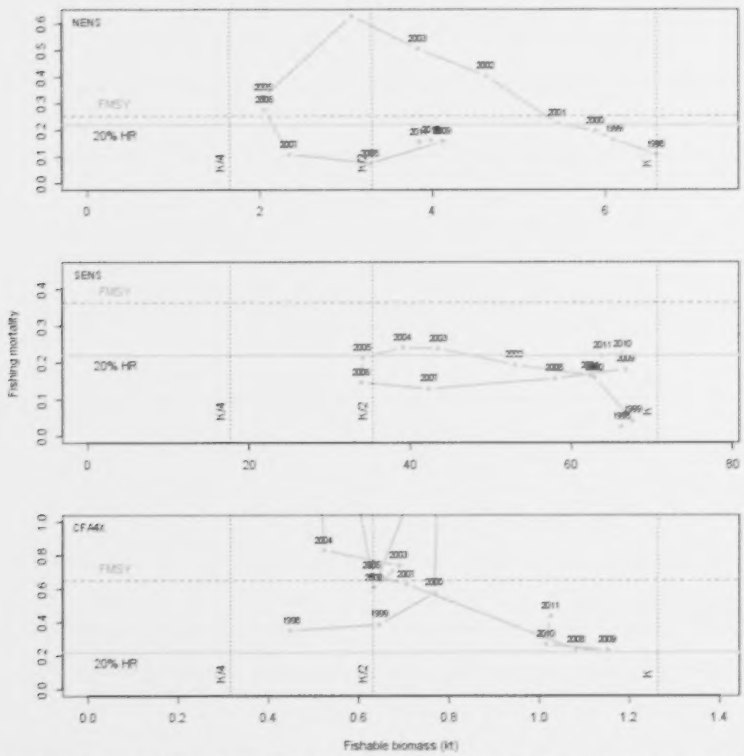


Figure 16. Fishing mortality as a function of fishable biomass for N-ENS (top), S-ENS (middle) and 4X (bottom).

The following exploitation-based reference points are suggested:

- Target Removal Reference (target RR): 20% of the fishable biomass (F=0.22), with secondary, contextual indicators altering harvest rates between 10 and 30% of fishable biomass (F=0.11 to F=0.36) where F is defined as the fishing mortality of the legal sized mature male population.

- Removal Reference (RR): not to exceed F_{MSY} (specific to each area) as stock collapses have been observed with this practice.

Harvest control rules (HCR) have been developed which link the biomass reference points to the exploitation reference points (Figure 17). In the Cautious and Healthy zones, actual target harvest rates are shaped by a suite of secondary indicators that provide more complete information on the entire stock's health. Secondary indicators are used to inform management decisions under the HCR linking the stock references to harvest strategies. Secondary indicators include expected recruitment, spawning stock biomass, size and age structure of various stock components, sex ratios, environmental variables, fishery performance and others. If a stock is determined to be in the Critical zone, all fishing activities cease with the belief that this will allow the stock to rebuild.

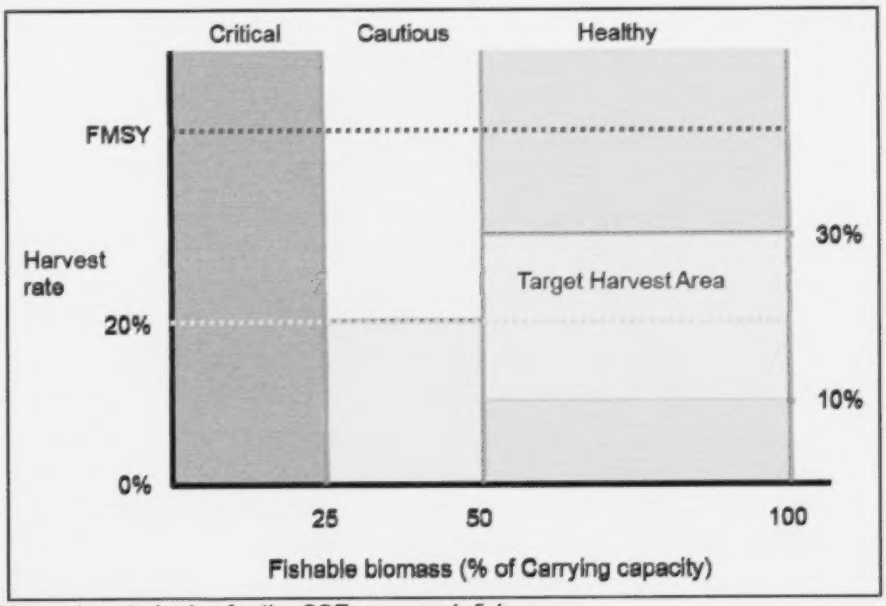
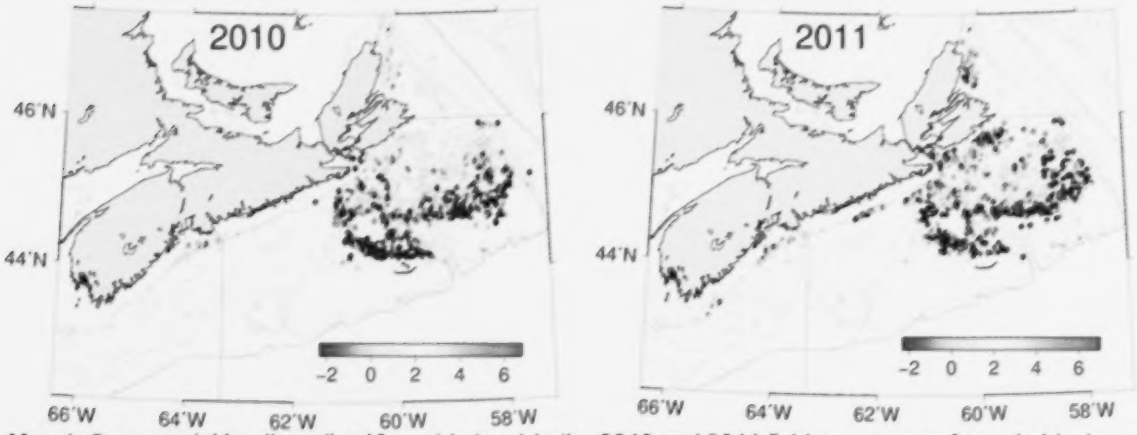
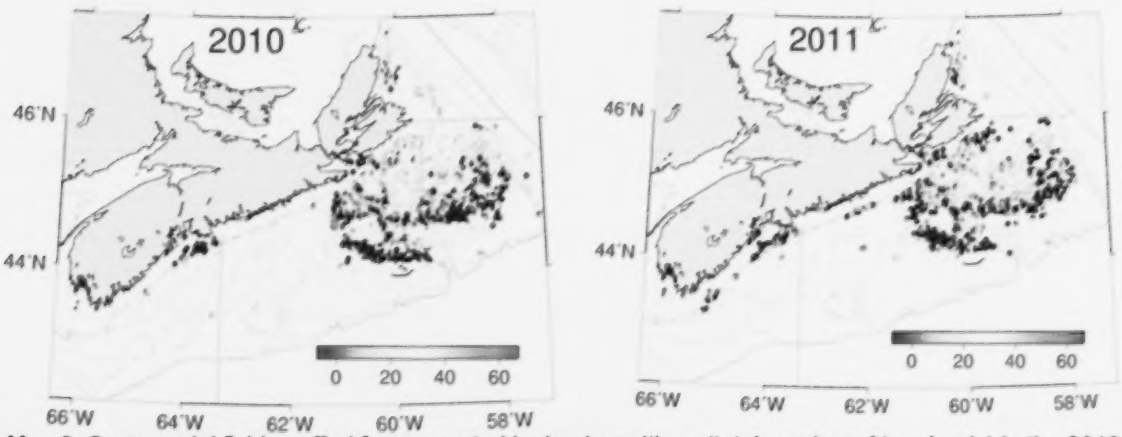


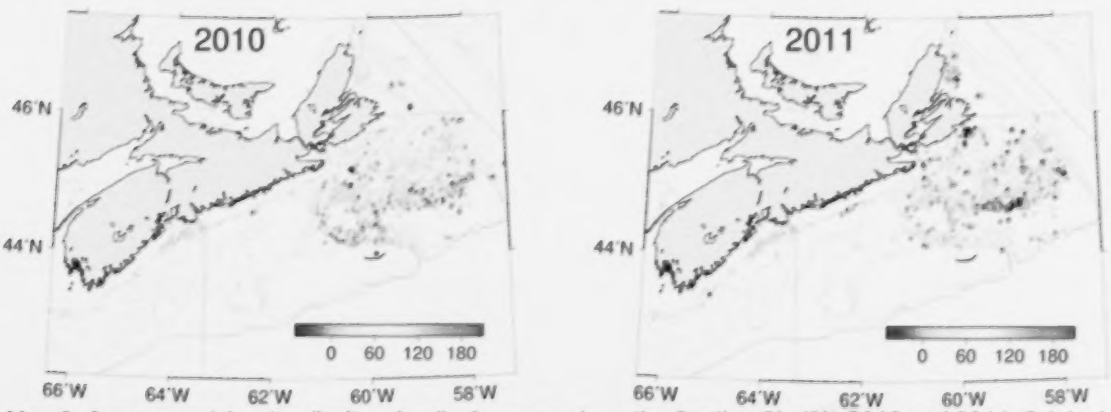
Figure 17. Harvest control rules for the SSE snow crab fishery.



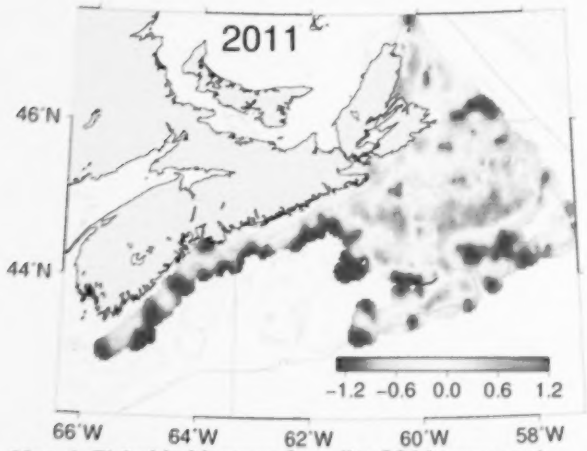
Map 1. Commercial landings (log10; metric tons) in the 2010 and 2011 fishing seasons. Areas in black are off the scale. Original figure in colour.



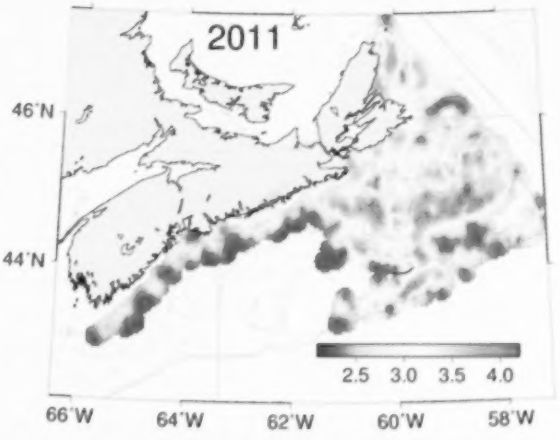
Map 2. Commercial fishing effort from reported logbook positions (total number of trap hauls) in the 2010 and 2011 fishing seasons. Areas in black are off the scale. Original figure in colour.



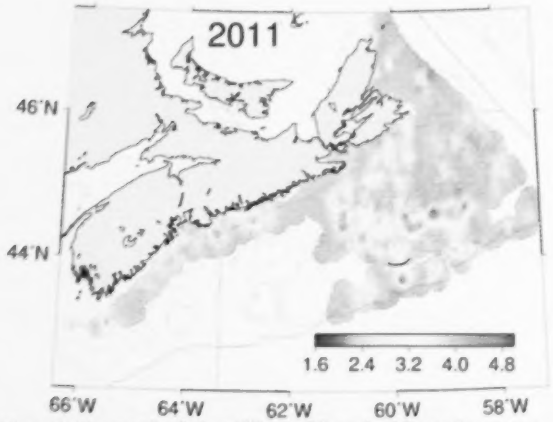
Map 3. Average catch rates (kg/trap haul) of snow crab on the Scotian Shelf in 2010 and 2011. Original figure in colour.



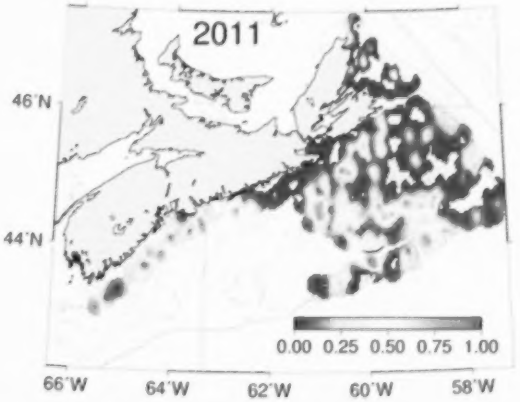
Map 4. Fishable biomass from the 2011 snow crab survey. Log 10 scale. Original figure in colour.



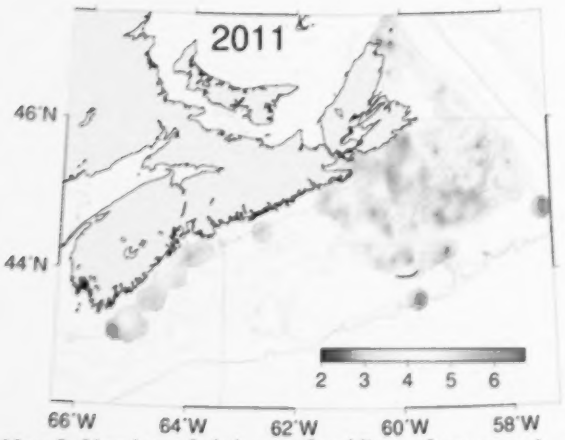
Map 5. Numerical abundance of recruitment of snow crab in 2011. Log 10 scale. Original figure in colour.



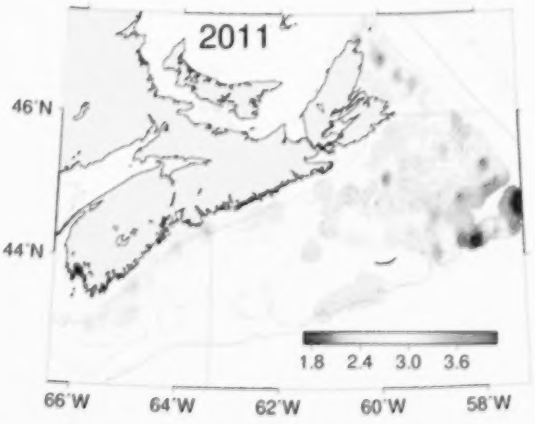
Map 6. Numerical densities of berried female snow crab. Log 10 scale. Original figure in colour.



Map 7. Proportion of females in the mature population. Note the heterogeneous distribution of sexes in all areas. Original figure in colour.



Map 8. Number of shrimp, a food item of snow crab. Log 10 scale. Original figure in colour.



Map 9. Number of thorny skate, a predator of snow crab. Log 10 scale. Original figure in colour.

SOURCES OF INFORMATION

This Science Advisory Report is from the 28 February 2012 Assessment of Nova Scotia (4VWX) Snow Crab. Additional publications from this process will be posted as they become available on the DFO Science Advisory Schedule at http://www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

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